Atomic Energy Control Board
P.O. Box 1046
Ottawa, Canada
K1P 5S9

Commission de contrôle de l'énergie atomique
C.P. 1046
Ottawa, Canada
K1P 5S9

INFO-0161

COST AND BENEFITS OF NUCLEAR REACTOR REGULATION IN CANADA

by

J.D. Harvie

Atomic Energy Control Board
Ottawa, Ontario

June 3, 1985

PAPER

COST AND BENEFITS OF NUCLEAR REACTOR REGULATION IN CANADA

A paper presented at the Canadian Nuclear Society Annual Conference, Ottawa, Ontario, June 3, 1985.

ABSTRACT

This paper summarizes information on costs associated with regulation of nuclear power reactors in Canada. The AECB perspective on the benefits of such regulation, both to the public and to the nuclear industry itself, is presented.

RÉSUMÉ

Le présent rapport rassemble des renseignements sur les coûts associés à la réglementation des réacteurs nucléaires au Canada et présente le point de vue de la CCEA sur les avantages d'une telle réglementation autant pour le public que pour l'industrie nucléaire.

COST AND BENEFITS OF NUCLEAR REACTOR REGULATION IN CANADA

J.D. HARVIE

Atomic Energy Control Board
Ottawa, Ontario

ABSTRACT

This paper summarizes information on costs associated with regulation of nuclear power reactors in Canada. The AECB perspective on the benefits of such regulation, both to the public and to the nuclear industry itself, is presented.

INTRODUCTION

There appears to be a perception in the Canadian nuclear industry that licensing requirements imposed by regulatory authorities have, in recent years, led to a significant increase in the cost of safety measures, to the extent that safety provisions are a major factor in the economics of the CANDU program.

This paper presents the best available information on the capital and operating costs associated with the regulation of nuclear power reactors in Canada. In addition, it presents a regulatory viewpoint on some of the benefits, both to the industry and to public safety, which have resulted from regulatory activities.

COSTS OF SAFETY AND REGULATION

A study to estimate the costs of safety and regulation in the nuclear industry in Canada has been carried out by SECOR Inc., under contract to the Atomic Energy Control Board (AECB)(reference 1).

This study examined the costs associated with radiation health, safety, and environmental measures in each part of the nuclear fuel cycle, including uranium mining, refining, fuel fabrication, and nuclear power generation. The approach used was to obtain accounting data from representatives of the industry to determine typical costs associated with health and safety in each part of the cycle.

Subsequently, these total costs were subdivided into those which would have been incurred by a prudent operator (PO) in the absence of external regulation, and those which were incurred only to satisfy regulatory requirements (marginal cost of regulation or MCR). This subdivision was calculated on the basis of information supplied by representatives of the nuclear industry.

For the study of the capital costs of nuclear power generation, the four-unit Pickering 'B' plant was selected as a typical example. The results of this study are summarized in Table 1. The conclusion was that about 10% of the total capital cost of the Pickering 'B' reactors was due to radiation health, safety, and environmental considerations. Breaking this down, 6.4% was estimated to be the cost which would have been incurred by a prudent but unregulated operator, with the remaining 3.6% being the marginal cost due to regulation.

TABLE 1

CAPITAL COST OF RADIATION HEALTH, SAFETY AND ENVIRONMENTAL CONSIDERATIONS

Cost Element	($000,000) Total	PO	MCR
i) Hardware Costs			
a) Equipment	35.0	11.0	24.0
b) Quality Assurance	16.0	10.0	6.0
ii) Engineering	22.2	9.5	12.7
iii) Research Program	5.0	-	5.0
iv) Interest Costs			
a) Construction Delays	159.4	150.0	9.4
b) Additional Hardware	39.3	16.4	22.9
v) Replacement Power			
a) Vacuum Building Inspection	5.0	-	5.0
b) Additional Delays	27.6	-	27.6
Total	309.5	196.9	112.6
Total as per Cent of Total Capital Costs ($3,097 x 10^6)	10.0	6.4	3.6

To estimate the costs of safety and regulation in an operating reactor, the Bruce 'A' plant in the year 1980 was chosen as an example. Table 2 summarizes the conclusions of that study. Approximately 9% of the total cost of producing electricity was due to radiation health, safety, and environmental measures, of which about one half was attributed to regulatory actions.

TABLE 2

BRUCE A (1980) COST OF RADIATION, HEALTH, SAFETY AND ENVIRONMENTAL MEASURES

	Total	PO ($000,000)	MCR
Lost Power	16.241	7.812	8.429
Fuel	4.781	-	4.781
Decontamination	3.354	3.354	-
Instruction	0.977	0.722	0.255
Radiation Control/ Health Physics	1.557	1.557	-
Safety System Maintenance	0.512	0.498	0.014
Management	0.993	0.288	0.705
Security	0.344	-	0.344
In-Service Inspection	0.750	0.375	0.375
Other	0.992	0.942	0.050
Total	30.701	15.548	15.153
% of Cost of Producing Electricity	8.9	4.5	4.4

The overall conclusion that can be drawn from this study is therefore that the cost of regulation of nuclear power reactors in Canada is a relatively small proportion of the total cost of producing power.

The accuracy of the detailed results of the SECOR study is limited, for several reasons. While the actual costs associated with safety are based on Ontario Hydro's data, it is not always possible to separate precisely money spent on safety from that spent for production purposes. For example, the study attributed the entire cost of both shutdown systems to safety, although experience at Pickering 'A' has shown that its shutdown system has contributed to electricity production by terminating several loss-of-regulation incidents which, in the absence of shutdown action, would have resulted in damage to reactor systems and consequential delays in re-starting the reactors. On the other hand, the cost of the reactor containment is not included as a safety cost, although the Pickering containment could make some contribution to safety following an accident by delaying releases of radioactive noble gases by 15 hours or more, and by making it possible to filter most of the radioactive iodines from a release.

Equally, the subdivision of these safety costs into those associated with prudent operation, and those due only to regulatory demands, involves considerable uncertainty, since it is based on the response by representatives of the licensee to a hypothetical question. The actions which would have been taken by licensees in safety matters if there had been no regulatory authorities would have been determined by a decision-making process within the licensee organization, and the results of such a process can only be estimated.

Furthermore, the study is based on two specific power stations, Pickering G.S. 'B' for the capital costs and Bruce G.S. 'A' in 1980 for the operating costs. In both cases there are unique aspects which significantly affect the results of the study, and indeed this would probably be the case for any specific reactor chosen. Nevertheless, it must be recognized that the costs may be different for different reactor projects.

Despite the above limitations, the SECOR study is the only study which has attempted to determine, in a rational and scientific fashion, the costs of safety and regulation in the Canadian nuclear power industry. While it cannot be claimed that the results are absolute or precise, it is considered that the conclusions are sufficiently accurate to give a reasonable understanding of the extent to which safety and regulation affect the overall costs of nuclear power generation.

The cost to Canadian taxpayers of operating the AECB itself is not included in the above estimates. This cost is sufficiently small, in relation to those discussed above, that it would not affect the conclusions.

BENEFITS OF REACTOR REGULATION

The following sections discuss some of the consequences of AECB regulation of the nuclear power industry which, in the view of the AECB, are of benefit to the industry or the public. While sections (2) and (3) are based on the SECOR study and refer specifically to Pickering 'B' and Bruce 'A' respectively, the other sections are more general and draw examples from several currently-licensed CANDU reactors.

It is not possible, on the basis of information currently available, to determine in a quantitative fashion the extent to which regulatory activities have reduced the frequency of incidents, radioactive emissions, or overexposures to workers or members of the public. This would require the answer to another hypothetical question regarding the frequency of such events in an unregulated industry. It is the view of the AECB, based on the examples which follow and other experiences, that the effect of regulation has been positive and significant, with resulting benefits to the public, and indeed to the nuclear industry itself.

1) Acceptance of Nuclear Power

The existence of a competent regulatory authority appears to be a necessary prerequisite for public acceptance of the CANDU nuclear power program. In public and parliamentary discussions on the safety of nuclear reactors, the independent assessment of reactor safety by the AECB is a factor important both to the credibility of the industry and its acceptance by the public or its representatives.

For example, the final report on the Safety of Ontario's Nuclear Reactors by the Select Committee on Ontario Hydro Affairs (reference 2) stated in its chapter on regulation of nuclear power safety that much of the Committee's confidence that the reactors operating in Ontario are 'acceptably safe' came from observing the depth of analysis and questioning that goes into the design. This report also concludes that one of the great strengths of the Canadian system is the competence and independence of AECB staff. The Committee recommended that the Government of Ontario urge the Federal Government to ensure that the AECB is adequately funded.

Similarly, Professor D.A. Meneley, Professor of Nuclear Engineering at the University of New Brunswick stated in his submission in support of the Point Lepreau II project to the Environmental Assessment Review Panel of the Federal Environmental Assessment Review Office (reference 3), "From direct and personal experience I can testify that the AECB staff are vigilant, knowledgeable, and rigorous in their insistence on high safety standards. Many hardware and procedure improvements have resulted from their examinations".

Equally, the export of CANDU reactors to other countries depends to some extent on the existence of appropriate and well-defined licensing requirements, and of a satisfactory licensing process, within Canada. Potential foreign customers frequently request information on the safety standards required by Canadian licensing authorities. CANDU reactors built in other countries have generally been required to be licensable in Canada or have been required to satisfy the same standards as a similar plant licensed in Canada.

2) Design features in SECOR study

The SECOR study identifies certain design features of Pickering 'B' which were included only

to satisfy regulatory requirements. Table 3 shows the major hardware costs for Pickering 'B', and the proportion of these costs which are related to safety and regulation. The most significant features which, according to the study, were incorporated to satisfy regulatory requirements, were the following.

TABLE 3

PICKERING B SAFETY COSTS - EQUIPMENT

($000,000)

System	Total Cost	Safety Costs FO	Safety Costs MCR	Major Contributors
SDS1	2.6	2.3	0.3	Complexity
SDS2	3.4	0.5	2.9	Redundancy
ECIS	12.0	8.0	4.0	High pressure, valves
Main heat transport	119.3	-	2.7	Seismic
Emergency water	2.7	-	2.7	Seismic
Emergency power	2.2	-	2.2	Seismic
Other safety-related systems	248.9	-	4.2	Seismic
Powerhouse Service wing	55.9	-	0.6	Seismic
Containment	71.7	-	2.4	Seismic, vacuum buildi[illegible]
Other	522.0	-	2.0	Seismic
Total	1041.0	11.0	24.0	

a) Seismic Qualification of Equipment

Ontario Hydro disputed the need for seismic qualification at Pickering 'B'. Accordingly, the cost of systems such as the emergency power system and the emergency water system, in addition to the cost of strengthening structures and attachments to cope with seismic forces, is attributed to regulation.

b) Trip Parameters on Shutdown Systems

The AECB requires that each shutdown system include two diverse trip parameters to detect postulated failures, where this is practicable. In the absence of such a requirement, Ontario Hydro would have included fewer back-up trip parameters on shutdown system 1 (SDS1). Furthermore, only neutronic instrumentation would have been incorporated in shutdown system 2 (SDS2), to cope only with severe loss-of-coolant or loss-of-regulation accidents. The AECB position was that both shutdown systems should be capable of coping with more frequent events such as loss of boiler feedwater, as well as events of low probability such as large loss-of-coolant accidents, for which the neutronic trips were designed. As a result, part of the cost of SDS1, and a high proportion of the cost of SDS2 are attributed to regulatory requirements.

c) Emergency Coolant Injection System (ECIS)

While Ontario Hydro would have installed a high-pressure ECIS at Pickering 'B', the system would have been less elaborate than that required to satisfy AECB requirements. In particular, the requirement to have duplicated injection valves to satisfy reliability requirements is attributed to regulation. Furthermore, Ontario Hydro would have commissioned the first reactor before the system was fully installed and thus would have avoided an estimated two-month delay with associated interest and replacement power costs.

In addition to these design aspects, a portion of the costs of quality assurance and engineering were attributed to the regulatory requirements. The study also indicates that Ontario Hydro participation in the CANDEV safety research program would not continue if the industry were not regulated. A portion of the cost of this program was attributed to the Pickering 'B' reactors.

3) Operational Aspects of SECOR Study

As shown in table 2, the major single regulatory cost associated with operation of Bruce 'A' in 1980 was due to lost power caused by regulatory requirements or restrictions. The largest single component of this cost was due to loss of production for inspection of the junction between the steam generators and the steam drum following incidents in which the allowable stresses in this junction were exceeded due to circumferential temperature differentials across the steam drum. These inspections are required by the ASME Boiler and Pressure Vessel Code in order to obtain assurance that the stresses have not reduced the integrity of the pressure vessel. The extent of inspection was greater than that which Ontario Hydro would have done in the absence of regulation.

The increased fuelling costs were largely due to limitations on channel power imposed to reduce the risk of overheating fuel, with resulting restrictions on neutron flux shape. Management costs include effort by Ontario Hydro head office staff and consultants on safety analyses and other licensing matters, which, in the year of interest, included a major study of unavailability of safety systems. In addition, costs associated with Ontario Hydro's on-site reliability unit are wholly attributed to satisfaction of regulatory requirements.

4) Design Features Accepted by Nuclear Industry

There are several features of reactor design and operation which were originally introduced as a result of regulatory requirements, and some of which were strongly opposed by the nuclear industry at the time of their introduction. Nevertheless, in the information given to SECOR Inc. by representatives of the industry, these features, other than those discussed in (2) above, were not identified as being in excess of what a prudent operator would do in the absence of regulation. It is therefore concluded that these features are now accepted as appropriate by the industry. The following are examples.

a) Heat Sinks

The original Bruce 'A' design had only a single auxiliary boiler feedwater pump supplied by class III power (i.e. power backed-up by standby generators). There was no other method of adding

water to the steam generators, or otherwise providing an adequate heat sink for the decay heat from the fuel, which did not rely on class IV power (i.e. power from the station turbine-generators or the electrical grid). Furthermore, operating procedures did not prohibit taking the single feed pump out of service for maintenance during reactor operation. Questions raised by the AECB led to the incorporation of an emergency boiler cooling system and to modifications to the maintenance cooling system to achieve reliable heat sinks which are not dependent on class IV power. Subsequent reactor designs include such features as a turbine-driven auxiliary boiler feed pump (Point Lepreau) or an inter-unit feedwater tie (Bruce B) to ensure a sufficiently reliable supply of water to the steam generators in the event that class IV power is unavailable.

b) Emergency Core Cooling Systems (ECCS)

After the design of Bruce 'A' was essentially complete, questions raised by the AECB about the analysis of the effectiveness of its ECCS led to the recognition by the licensees that the gravity-fed system was not capable of satisfying its original design requirement, which was to prevent significant fuel failures following any loss-of-coolant accident. Nevertheless, Ontario Hydro considered the system to be adequate, and was opposed to making changes to make the system more effective. The AECB finally placed a requirement on Ontario Hydro to install an improved system as a condition of the approval to operate the Bruce 'A' reactors at full electrical power.

It is now generally recognized that low-pressure injection systems cannot be shown to be sufficiently effective, particularly for small-break loss-of-coolant accidents, which are much more likely to occur than large-break loss-of-coolant accidents because of the large amount of small-diameter piping in CANDU reactors. High-pressure emergency coolant injection systems are now being installed on all commercial CANDU reactors, even those outside Canada where the AECB does not have jurisdiction.

The recognition that the original design requirement of preventing significant fuel failures could not be satisfied by the gravity-fed system (and indeed for some types of loss-of-coolant accident even by a high-pressure system) led the AECB to request Ontario Hydro to conduct a systematic design review of the Bruce 'A' plant. The objective of this review was to identify design decisions which had been made on the basis of the original design requirements and which might have been inappropriate if these requirements were not met. Ontario Hydro was very strongly opposed to such a review.

When, following AECB insistence, the design review was carried out, it revealed, among other things, that the location and shielding arrangements of the emergency cooling system recirculation piping and the vapour recovery system ducting were completely inappropriate in the event that a large number of fuel failures occurred. Radiation from fission products in this piping would have resulted in unacceptably high radiation fields in the main control room and other critical areas of the plant. As a result, immediate changes were made to emergency procedures, and shielding was installed to make these areas habitable. At Darlington, most of the corresponding ECCS piping is now located in a well-shielded trench at a low elevation.

The need for an effective heat sink for emergency core cooling systems was also identified as a result of AECB review of the Bruce 'A' design. This emergency cooling system design was originally based on the concept that the vault coolers would act as the heat sink by condensing steam released from the primary heat transport system. However, this mode of operation proved difficult to analyze, and in any case it was subsequently noted by AECB staff that excess water from the dousing tank would most likely result in flooding of these coolers, which are located at a low elevation. At the time of reactor start-up, it was proposed that a heat sink be achieved by filling the secondary side of the steam generators and the steam piping with water. Obvious difficulties presented by this approach led to a request by the AECB to install dedicated heat exchangers as part of the emergency core cooling system. This approach has been followed in reactors licensed since that time.

5) Correction of Design and Manufacturing Errors

Several errors in design and manufacturing have been identified and corrected as a result of tests and analyses required by the AECB. The following are examples.

a) Dousing System Fibreglass Risers

At Bruce 'A', the fibreglass risers between the dousing tank and the upper vacuum chamber were not designed to withstand the pressure differential to which they are subjected when the system operates, due to a design error. Licensees did not propose to conduct a full-scale commissioning test of the dousing system because of its apparent simplicity. Nevertheless, the AECB insisted that such a test be done. The test revealed the design error when the fibreglass risers failed, preventing dousing from taking place.

b) Emergency Coolant Injection System

At both Point Lepreau and Gentilly-2, the AECB required that a commissioning test of emergency injection into the primary heat transport system be conducted, despite opposition to such tests by the licensees. The tests revealed that, for a small-break loss-of-coolant accident, pressure oscillations in the heat transport system resulted in the injection valves opening in a series of short steps rather than in a continuous fashion. In addition, flow meters for which the design was appropriate for a large break proved incapable of verifying the rate of flow in the injection lines for the more likely small-break situation.

c) Regional Overpower Flux Detectors

Commissioning tests at high power were conducted at Point Lepreau and Gentilly-2, to ascertain the accuracy of the predictions of flux shape and channel powers for various configurations of reactivity control devices. AECB staff questioned certain results of these tests which appeared to be anomalous in that the change in flux was in the

opposite direction from that predicted. Following these questions, it was discovered that the anomalies were due to the fact that several regional overpower flux detectors were connected to the wrong channels of one of the shutdown systems of both reactors.

CONCLUSION

The cost of regulation of nuclear power reactors in Canada is a relatively small proportion of the total cost of producing power. It is the opinion of the AECB that regulatory activities have resulted in benefits to the industry, in terms of public acceptance of the CANDU program, and to the safety of reactor workers and the public.

REFERENCES

(1) SECOR INC., "Estimating the Costs of AECB Regulation", INFO-0023-2, April 1981.

(2) SELECT COMMITTEE ON ONTARIO HYDRO AFFAIRS, "The Safety of Ontario's Nuclear Reactors, Final Report", June 1980, Chapter 3, pp 37, 39.

(3) MENELEY, D.A., University of New Brunswick, Submission to Assessment Review Panel, Federal Environmental Assessment Review Office, November 13, 1984.